Review

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Review

Classical and Quantum Views of Information from the Observer's Point of View

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Abstract: This paper explores classical and quantum entropy through the lens of relativistic observer-dependence. By modeling a qubit-populated spherical system, we analyze entropy as perceived by spatially separated observers, introducing time-delay effects in information acquisition. Shannon and von Neumann entropies are formulated as observer-dependent functions, and a framework is proposed for the spatiotemporal propagation of informational entropy. The work emphasizes that entropy, typically viewed as a scalar or global property, acquires field-like behavior when relativistic considerations are included.

1. Introduction

Entropy is foundational in both classical and quantum theories of information. While Shannon entropy quantifies uncertainty over a discrete set of events [1], von Neumann entropy extends this idea to quantum systems via density matrices [2]. However, in relativistic settings, simultaneity is not absolute, and information transmission is constrained by the finite speed of light. Thus, the entropy an observer perceives may differ from the system's actual state. Inspired by works on relativistic quantum information [3][4], this paper formalizes entropy as a space-time-dependent quantity, introducing observer-relative formulations in both classical and quantum contexts.

2. Entropy in Classical Information Theory

Let be a binary alphabet, and a discrete random variable over with probability distribution . Shannon entropy is given by:

Assuming the system is at position and the observer at , the distance , and information travels at speed , the perceived entropy is delayed:

This observer-relative entropy formulation aligns with causal constraints in relativistic theories.

3. Quantum Information: von Neumann Entropy

Quantum states are described by density matrices , with .

The von Neumann entropy is:

where are eigenvalues of . The entropy perceived by a distant observer becomes:

This reinforces the observer-dependence of quantum entropy, as previously suggested in relativistic quantum frameworks [3][5].

4. Time Evolution and Dynamics

Classical Example: A binary Markov process with flip rate has:

Inserting into gives .

Quantum Example: For unitary evolution , if is diagonal, entropy is constant. For open systems with Lindblad dynamics [6]:

where introduces decoherence, yielding time-varying entropy. Observed entropy remains:

5. Observer-Relative Entropy Field

We define a scalar entropy field over space-time:

This function is discontinuous along light cones and introduces **entropy horizons**—surfaces of constant information delay. This idea resonates with causal structure in space-time [4].

6. Entropy Gradient and Information Flux

The spatial gradient of entropy defines an information flux field:

This captures how perceived entropy changes with observer position, indicating an informational field propagating in space-time, akin to light cone fronts.

7. Conclusion

Both classical and quantum entropy are observer-relative when relativistic constraints are incorporated. Perceived entropy depends on the observer's position and the finite speed of information. This formalism introduces a field-like perspective on entropy, opening pathways for further applications in cosmological entropy gradients, black hole thermodynamics [5][7], and relativistic quantum communication [3][9].

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